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# EXPERIMENTAL INVESTIGATION OF ENHANCEMENT HEAT TRANSFER BY NATURAL CONVECTION FROM FOUR FINNED CYLINDERS IN A VERTICAL ARRAY PLACED IN A CONDUIT

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Original Article

***ABSTRACT***

***In this research, experiments have been implemented to enhance heat transfer by free convection from four finned cylinders that have helical fins, fixed horizontally inside conduit and using air as working fluid, the cylinders heated by electrical heaters at constant heat flux (188,341,573,832)W/m$^2$for Rayleigh number from ($5X10^4$ to $11.5X10^4$) and Prandtl number (0.71)at the ambient temperature, approximately (24–26)°C and pressure at (1 atmosphere). The investigation include designed and manufactured test model, consist from two parts: moving and stationary, the stationary part is a frame made from iron that allows to move the part to inside it, according to ratio(H/D). The ratio (Y/D) changed four times (Y/D=2,4,6,8), the ratio (X/D) changed four times (X/D=1.5,3,5,7) and the ratio (H/D) changed four times (H/D=15,20,25,30). The results showed for all values of heat fluxes, the heat transfer coefficient and Nusselt number increases at separation distances (Y/D=4) & (X/D=3), which gives greater heat transfer rate, and any increasing or reducing lead to reduction in heat transfer rate. But regarding the ratio (H/D), the results showed there was no obvious influence or simple influence on heat transfer. Also, the results showed increased Nusselt number, with increasing Rayleigh number for all cylinders. The experiments have been implemented for single cylinder, placed in free air under constant heat flux, calculated ($Nu_o$) and compared it with ($Nu_i$) for cylinders arranged in vertical array at the best case (Y/D=4) & (X/D=3) under the same heat flux ($\tilde{q}$=341,573,832)W/m$^2$. The results show, there was obvious enhancement for the cylinders arranged in vertical array compared with singular cylinder in heat transfer, furthermore, this enhancement increases with increasing (Ra). From the results, empirical equation was found, to calculate the value of ($Nu_{mean}$) that includes the two variables with ($Ra_{mean}$) as follows: $Nu_{mean}$= 0.765Ra0.2 (Y/D) 0.08 (X/D) 0.01 (5X104≤ Ra ≤ 11.5X104).***

***KEYWORDS: Enhancement, Heat Transfer, Natural Convection Z & Finned Cylinders***

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## Symbols

| | |
|---|---|
| D | The outer diameter of fin (30 mm). |
| H/D | The vertical distance ratio between the test rig and floor to diameter |
| $h_{mean}$ | Mean heat transfer coefficient (W/m$^2$. °C) |
| $K_f$ | The thermal conductivity for air at film temperature |
| $Nu_{mean}$ | Mean Nusselt number of cylinder where $\mathbf{Nu_{mean}}=\frac{h_{mean}.D}{K_f}$ |
| $Nu_i/Nu_o$ | The ratio of mean Nusselt number of cylinder in array to mean Nusselt number of cylinder in free space |
| $Ra_{mean}$ | Mean Rayleigh number where $\mathbf{Ra = Gr.\ Pr} = \frac{g.\beta.\Delta T.D^3}{\nu.\alpha}$ |
| X/D | The horizontal distance ratio between the cylinders and the walls to diameter |
| Y/D | The vertical distance ratio between the cylinders to diameter |

## 1. INTRODUCTION

Natural or free convection is still a problem in engineering applications. Heat transfer from different geometries has been investigated, and due to the small heat transfer coefficients, the procedures have been advanced to enhance the heat transfer rate. One of the problems in recent years is natural convection heat transfer from a single cylinder or from arrays of cylinders [1]. Due to the importance of using the cylinder, investigations have continued to get best results in order to achieve dispelling the biggest amount of heat, by consuming the lowest amount of energy. Hence, it brings the attention of researchers to study heat transfer by free convection, from a cylinder and arrays of horizontal cylinders by investigating the distance between the cylinders and effect of set the row inside the conduit [2].

Many previous investigations done to enhance the heat transfer and therefore reduce the spent energy. Stig and Atle [3] performed an experimental study of natural convection heat transfer of a vertical array of three evenly horizontal cylinders, with dissimilar cylinder separation distance. Nusselt numbers were carried out at Rayleigh numbers $1.96\times10^{7}$and $5.35\times10^{7}$and at separation distances (2D, 3D, 4D, 5D). The results showed that in the three-cylinder array, the Nusselt number of the second cylinder increased compared to the upper cylinder for two Rayleigh numbers carried out and for all separation distances. The Nusselt number of the upper cylinder in array increased compared with the lower unconfined cylinder, but was comparable with the middle cylinder at the separation distances carried out. Butler et. al.[4], experimentally studied for free convection heat transfer from a heated horizontal cylinder fixed in a square container, where the variance of temperature founds through its perpendicular walls has $Ra_{cy}$ domain between $2x10^{4}$ to $8x10^{4}$ and the value of Prandtl number (0.71).

The measurements of temperature and Nusselt number for cylinder were took at a domain of ϴ*. ϴ* is known as a fraction of cylinder and container Grashof numbers. They display more interfering between the structure of stream created by the cylinder and by the container with mounting ϴ*, identical to the rise in the heat dissipation from the cylinder. The outcomes showed that the values of Nu suitable to the correlations at the lesser values of $Ra_{cyl}$, but when $Ra_{cyl}$ raise Nu rise to comparison with the correlations. Satyanarayana et. al [5], experimentally studied for natural convection heat transfers from array of perpendicular tubes for different inclination angles. The inclination angles were changed from $0^{0}$–$45^{0}$angles with steps of 15 degrees. The tests were implemented on a special advanced place to get constant heat flux and measured the temperatures by thermocouples.

The tests are implemented for (Ra) from $4.5x10^{4}$ to $8.5\ x10^{8}$. The influences the angle of inclined array and Rayleigh number on the distribution of temperature were studied. The local (Ra) and (Nu) were evaluated along the tube length. It was observed that the temperatures along the tube array increase up to a certain height and decreases for all inclinations, and this decrease is prominent at high inclinations due to the turbulence generation. It is found that for higher values of Ra and higher inclination angles, the temperature differences from the tube to atmosphere decreases, due to the disturbances of turbulent boundary layer. The local (Nu) of tube array increases with increase in (Ra), and at higher inclinations, the increase of (Nu) is very significant. Ali and Yasin, [6], investigated experimentally natural convection heat transfer in an inclined open cylindrical passage with constant heat flux to investigate the inclination angle effect and heat flux on heat transfer. Heat transfer results were presented for the inclination angles of (0º–30º–60º–90º), using cylinder diameter of 4.8 cm cylinder length 50 cm and heat flux from 70 $W/m^{2}$ to 600 $W/m^{2}$.

The results showed that when the heat flux increased and inclination angle changed from (0º to 90º) both of local and average, Nusselt number increased. So the heat transfer process enhanced, as heat flux increased and the inclination

angle moves from (0°–90°). Kitamura et. al [7] investigated experimentally free convective flow and heat transfer output around a heated horizontal cylinders fixed in perpendicular array. The tests were implemented with the array consist of 10-cylinder of diameters (D = 8.4, 14.4, 20.4) mm. The cylinder array were put in air with perpendicular distances (G between 3.6 and 150.6) mm. These allowed to do the tests, in the wide ambit of the adjusted (Ra) between $5x10^2$ to $10^5$ and the non-dimensional distances (G/d) = 0.176 to 17.9. At first, the stream fields around the array were photographed by using a smoke. The outcomes showed that the generated columns from the upstream cylinders stay laminar along the array when the distances between cylinders are lesser than 20.6 mm. While the distances are greater than 30.6 mm, the columns start to wobble and changed to the troubled transmission on the midway of the array. Results of study depicted that the Nusselt numbers decrease monotonously toward down-stream when the flow remained laminar. When the flow undergoes turbulent transition on the halfway of the row, the Nusselt numbers are increased significantly. Surya et. al.[8]'s experimental study has been achieved with singular, two cylinders sited contiguous to each other with changing center-to-center distances and three cylinders placed in a triangular arrangement to measure the interference of natural convection-based heat transfer rates around array of heated cylinders have been investigated.

The outcomes displayed for tests including two cylinders, a powerful reliance of the heat transfer by convection mode on the separation distance between the cylinders. Also, the results showed that the rates of heat transfer from the upper cylinder were powerfully affected by the thermal plumes, which rise from the lowest cylinders. The mean Nusselt number of the singular cylinder was found to be clearly more than the mean Nusselt number, surrounding the upper cylinder in triangular arrangement

## 2. EXPERIMENTAL APPARATUSES

### 2.1. Apparatuses

The experimental rig is designed and manufactured by the researcher in the labs of the college of engineering in university of Was it, and the tests of this investigation have been carried out in this laboratory under the circumstances of lab, the temperature ranging (25–27)ºC and atmospheric pressure (1 bar).

### 2.2. Test Section

#### 2.2.1. Moving Frame

Consists from four walls, two square walls from glass with iron frame, its dimensions (1200×1200×8) mm length, width and thick respectively, and two walls made from wood with dimensions (1200×10) mm length and thick respectively, with variable width according to the ratio(X/D), from cylinder fixed horizontally in array (heat exchanger) inside the duct, as shown in figure 3.

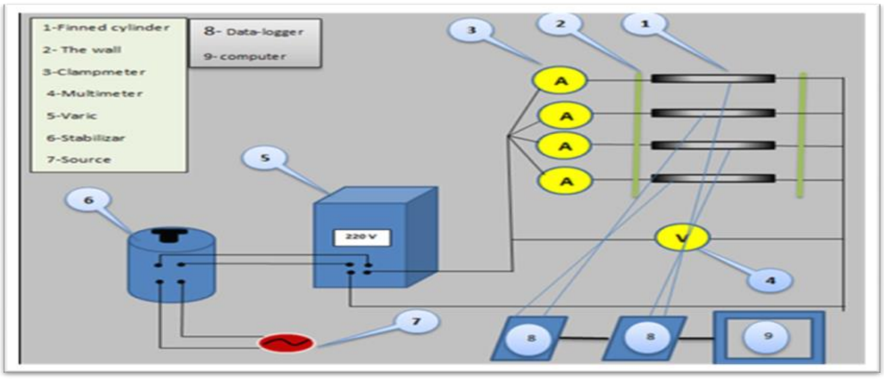


**Figure1: Schematic Diagram for the Experimental Test Rig.**

### 2.2.2. Stationary Frame

Made from iron, as a hollow cube shape allows to moving part to move manually inside it up and down, according to the ratio (H/D). Also, shows the variable distances (X, Y, D).

### 2.2.3. Finned Cylinders

The heat exchanger consists of four horizontal finned cylinders fixed inside moving frame in variable distance, the cylinders are made from mild steel, length of cylinder is (500mm), and the length of finned section of the cylinder is (360mm). Fins used is spiral type, the inner diameter of cylinder is (10mm), the outer diameter of cylinder is (12mm), the inner diameter for fins is (12mm), the outer diameter for them is (30mm) and the number of fins along the cylinder(66). The fins used are annular with meander, fins installed on the cylinder by twist ribbon it's :(length 1760 mm), width (9mm) and thick (0.5mm), and thus get finned tube for heating the surface of heat exchanger. Proven electrical resistance file type (Ni-Cr) and used ($MnO_2$) a high thermal conductivity material as electric insulator separates the electric coil and the tube, the finned cylinder is shown in figure 5. It is connected with the ends of electrical resistance by wires for each side, and for reducing conduction losses, white ceramic material of thickness (10mm) at a diameter equal to the cylinder diameter, and the four finned cylinders are fixed by two plate of wood.

### 2.2.4. Measuring Devices

Figure 4 show the measuring devices used in this research when a: electricity stabilizer used to supply (AC) power stable coming from thermocouples and sending it again to computer to record the temperature for the selected point by Picolog 6 beta software program, d & e: thermocouple reader were used to read temperature and f: digital clamp meter used to measure the current passing through the heater.

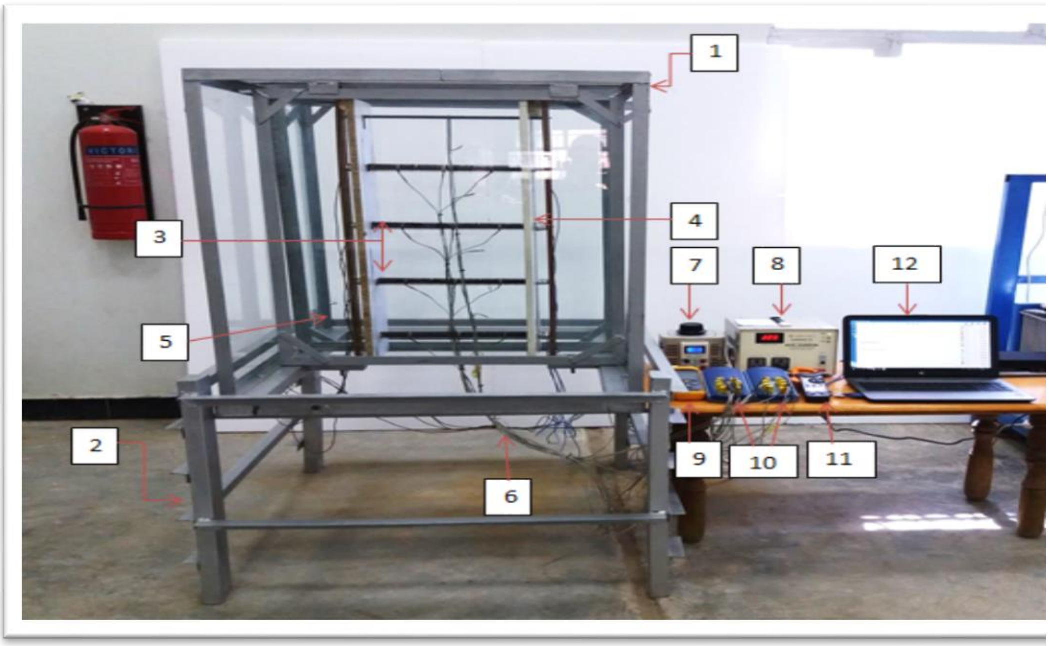


**Figure 2: Picture for the Experimental Test Rig**
**(1) Moving Frame (2) Stationary Frame (3) Finned Cylinders (4) Wood wall (5) Glass wall (6) Thermocouples wires (7) Variac (8) Stabilizer (9) Thermocouple Reader (10) Data-logger (11) Clamp meter (12) Computer.**

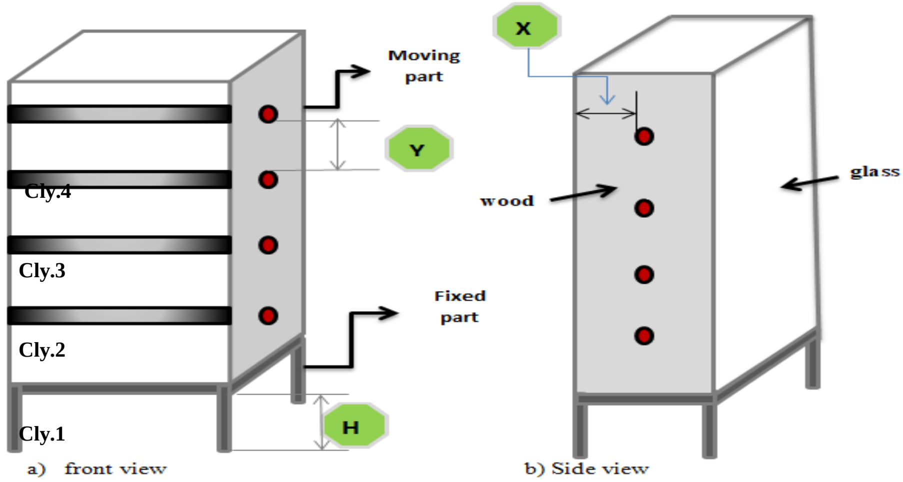


**Figure 3: Schematic Diagram for Test Section for Four Finned Cylinder fixed inside an Enclosure in Vertical Array.**


**Figure 4: Apparatuses which used in this Research.**

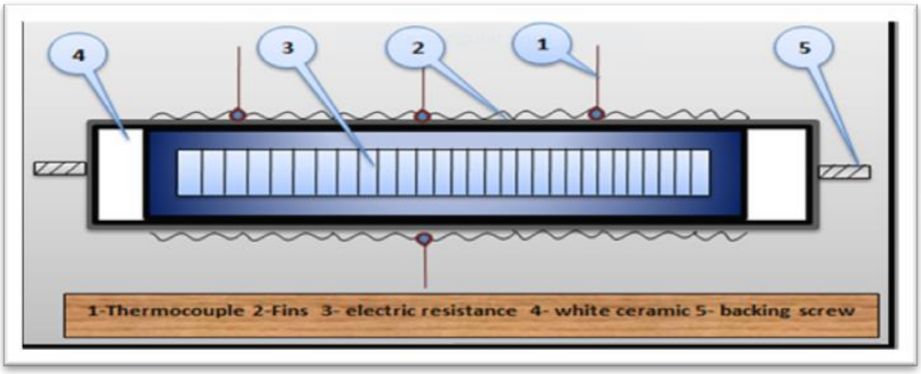


**Figure 5: Section of Finned Cylinder**

## 3. EXPERIMENTAL PROCEDURE

The first step is monitoring the surroundings temperature of the lab and make sure the stagnant air existence to natural convection that takes place without any air movement on top of the experimental section, and then set up all the apparatuses and tools of the test in the suitable venue, with the accordance of test requirements and operational circumstances to make sure a typical and secure process. Make sure from the joining of all connection for cables and other needful parts from the screws and bolts tightening, and check the readiness of measurement devices. Equip AC power to the electricity stabilizer to supply a steady energy to the voltage transformer (variac) apparatus. Steady state is achieved after (4-5) hours record the temperature by data-logger, reading the temperature by computer and recording the readings in form of the practical tests for project. The first 16th experiments the ratio (Y/D=2) and the ratios (X/D) has changed four times (X/D=1.5, 3, 5, 7) and change the heat flux four times. The second 16th experiments (Y/D=4), the ratios (X/D) has changed four times (X/D=1.5, 3, 5, 7) and change the heat flux four times. The third 16th experiments, the ratio (Y/D=6) and the ratios (X/D) has changed four times (X/D=1.5, 3, 5, 7) and change the heat flux four times. The fourth 16th experiments the ratio (Y/D=8) and the ratios (X/D) has changed four times (X/D=1.5, 3, 5, 7) and change the heat flux four times. Changed the ratio (H/D) four times (H/D =15, 20, 25, 30) with fixation of the ratios (Y/D &X/D) from the previous experiments and locate the best ratio (H/D), which give the best heat transfer. At the end of experiments, the researcher got the best ratios (Y/D), (X/D) and (H/D), which gives the best heat transfer from the four cylinders. At last, four experiments for single cylinders in free air have been done for four value of heat flux.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Effect of Varying the Ratio Y/D

The ratio (Y/D) have been changed four times (Y/D=2, 4, 6, 8) and the ratio (X/D) has been changed four times (X/D=1.5, 3, 5, 7) for each ratio of (Y/D), and the heat flux changed four times ($\tilde{\tilde{q}}$=188, 341, 573, 832) W/m$^2$ for each experiment. The results are as follows:

- **Heat Transfer Coefficient Distribution**

Figure 6 shows the mean heat transfer coefficient for each finned cylinders at varied (Y/D) ratio. At (X/D=1.5) ($\tilde{\tilde{q}}$=188 W/m$^2$), increases with increase (Y/D), until reaches to maximum value at (Y/D=4), which represent the optimum value and then it begin to decrease. This may be due to good mixture of air circulation in this distance and turbulent generation occurrence. The figures7, 8 & figure9 for the other ratio of (X/D=3, 5, 7) and ($\tilde{\tilde{q}}$=188 W/m$^2$) it shows the same behavior and the same results, where the maximum mean heat transfer coefficient at (Y/D=4) represent the optimum value, but it can be seen that the maximum value for heat transfer coefficient was at figure.6, this value was 12 W/m$^2$. K for first cylinder at the optimum.

The result shows for the other heat flux value ($\tilde{\tilde{q}}$=341, 573, 832) W/m$^2$ and for all ratios of (Y/D) & (X/D), the mean heat transfer coefficient shows they have the same behavior, and it was noted as the best value of the distance in vertical direction at (Y=4D), which gave greater mean heat transfer coefficient, as example, the figure 10 shows the value for ($\tilde{\tilde{q}}$=832 W/m$^2$) and figure 11 shows for value of ($\tilde{\tilde{q}}$=573W/m$^2$).

- **Nusselt Number Distribution**

Figure 12 shows the mean Nusselt number for each finned cylinders at varied (Y/D) ratio and at (X/D=3) ($\tilde{\tilde{q}}$=188 W/m$^2$), it increases with increasing (Y/D), until reaches to maximum value at (Y/D=4), which represent the optimum value and then it begin to decrease. The maximum value of $Nu_{mean}$ for cylinders 1,2,3,4 were 12.6, 10.5, 8.9 & 7 respectively.

The results show of the other heat flux value ($q^{\approx}$=341,573,832) W/$m^2$and for all ratios of (Y/D) & (X/D), the mean Nusselt number have the same behavior, and it was noted the best value of the distance in vertical direction at (Y =4D), which gave greater mean Nusselt number, as example figure 13 shows for value of ($q^{\approx}$=341 W/$m^2$).

**4.1.1. Effect of Varying the Ratio X/D**

The ratio (X/D) have been changed four times (X/D=1.5, 3, 5, 7) and the ratio (Y/D) has been changed four times (Y/D=2, 4, 6, 8) for each ratio of (X/D), and change the heat flux 4 times ($q^{\approx}$=188,341,573,832) W/$m^2$ for each experiment, the result shows.

- **Heat Transfer Coefficient Distribution**

Figure14 shows, the mean heat transfer coefficient for each finned cylinders at varied (X/D) ratio and at (Y/D=2) ($q^{\approx}$=188 W/$m^2$) increases with increasing (X/D), until reaches to maximum value at (X/D=3) which represent the optimum value, and then it begin decrease due to the chimney effect on the air flow inside the conduit.

The figures 15, 16& figure 17 for the other ratio of (Y/D= 4, 6, 8) and ($q^{\approx}$=188 W/$m^2$), it shows the same behavior and the same result, where the maximum mean heat transfer coefficient at (X/D=3) represent the optimum value because, the air velocity was maximum at this distance.

The results show for the other heat flux value ($q^{\approx}$=341,573,832)W/$m^2$ and for all ratios of (Y/D) & (X/D), the mean heat transfer coefficient shows the same behavior, and it was noted as the best value of the distance in vertical direction at (X =3D), which gave greater mean heat transfer coefficient, as example, figure 18 shows the value of ($q^{\approx}$=341 W/$m^2$) and figure 19 shows the value of ($q^{\approx}$=573W/$m^2$).

- **Nusselt Number Distribution**

Figure 20 shows the mean Nusselt number for each finned cylinders at varied (X/D) ratio and at (Y/D=4) ($q^{\approx}$=188 W/$m^2$) increases with increasing (X/D), until reaches the maximum value at (X/D=3), which represents the optimum value and then it begin to decrease. The maximum value of $Nu_{mean}$ for cylinders 1,2,3,4 were 12, 10.2, 8.5 and 6.6, respectively.

The results show, for the other heat flux value ($q^{\approx}$=341,573,832)W/$m^2$and for all ratios of (Y/D) & (X/D), the mean Nusselt number have the same behavior, and it was noted as the best value of the distance in vertical direction at (X=3D), which gave greater mean Nusselt number, as example figure 21 shows for value of ($q^{\approx}$=341 W/$m^2$)

**4.1.2. Effect of Varying the Ratio H/D**

Figure 22, which represent the variation of temperature for different value of (H/D) and (Y/D=4) & (XD=3) at ($q^{\approx}$=376 W/$m^2$) shows, there was no obvious influence or there was simple influence for change the ratio (H/D), where the ratio (H/D) changed four times (H/D=15, 20, 25, 30), so no need to change heat flux value.

**4.1.3. Effect of the Men Rayleigh Number on the Men Nusselt Number**

Figure 23 shows the effect of the men Rayleigh number on the men Nusselt number for four finned cylinders, which was arranged as vertical array inside conduit, under four value of constant heat flux, and for all (Y/D=4) & (X/D=3) ratio when the men Rayleigh number increases, the men Nusselt number also increases.

### 4.2. Comparison between the Cylinders Arranged in Array with Singular Free Cylinder

Figures 24 shows the comparison between the four finned cylinders, arranged as vertical array inside conduit, at the best case (Y/D=4) & (X/D=3), under different value of constant heat flux with singular cylinder placed in free air with different value of Rayleigh number. It was clear, there was good enhancement in heat transfer ($Nu_i/Nu_o$), founded as follow (1.56 to 1.68) for cylinder no.1 and (1.30 to 1.41) for cylinder no.2 and (1.16 to 1.30) for cylinder no.3 for the cylinders placed in vertical array comparing with singular cylinder placed in free air. Furthermore, it was noted that the heat transfer enhancement increases with increasing Rayleigh number.

By using the MATLAB program, the results of experimental work are governed by empirical equations for four finned cylinders, which it arranged as vertical array, made of mild steel inside conduit under constant heat flux. The distance between the cylinders has been varied (Y=2 D, 4 D, 6 D, 8 D) and the separation distance between the walls and the cylinders has been varied(X=1.5D, 3D, 5D, 7D) with four value of constant heat flux (188,341,573,832) W/m$^2$.

$$\mathbf{Nu_{men} = 0.765Ra^{0.2}\,(Y/D)^{0.08}\,(X/D)^{0.01}\quad (5X10^4 \le Ra \le 11.5X10^4)}$$

### 4.3. Validation of Present Study

Comparing the varied distance between cylinders (Y/D) with reference Stig & Atle [3] for mean value of Nusselt number of cylinder, the comparison showed good agreement concerning Nusselt number behavior along the cylinders, where both studies showed that the Nusselt number increases with increasing the distance between cylinders until reach to optimum distance and then there was degrease in Nusselt number with increase in the distance, as shown in figure25.

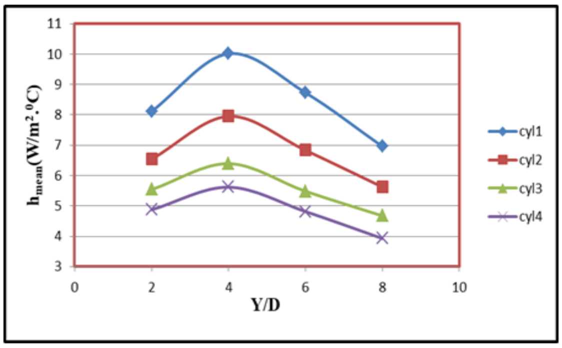


**Figure 6: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=1.5) ($q^{\approx}$=188 W/m$^2$).**

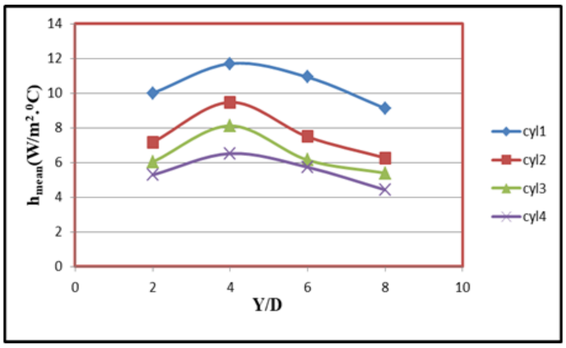


**Figure 7: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=3) ($q^{\approx}$=188 W/m$^2$).**

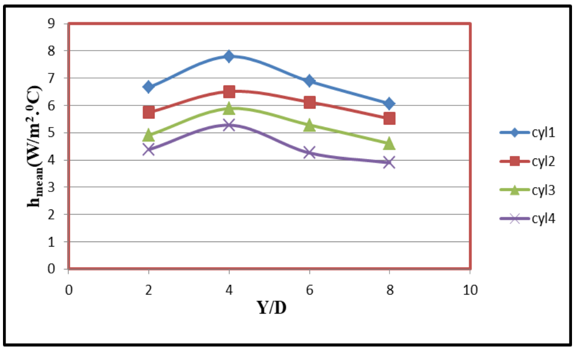


**Figure 8: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=5) ($q^{\approx}$=188 W/m$^2$).**

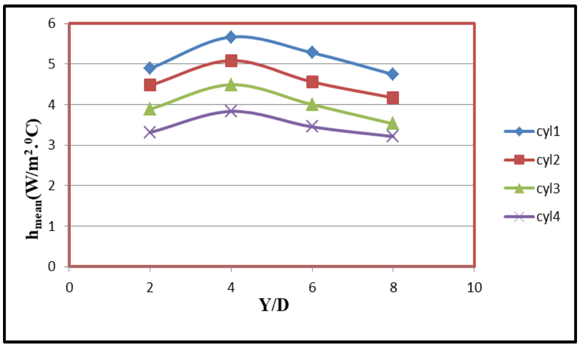


**Figure 9: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=7) ($q^{\approx}$=188 W/m$^2$).**

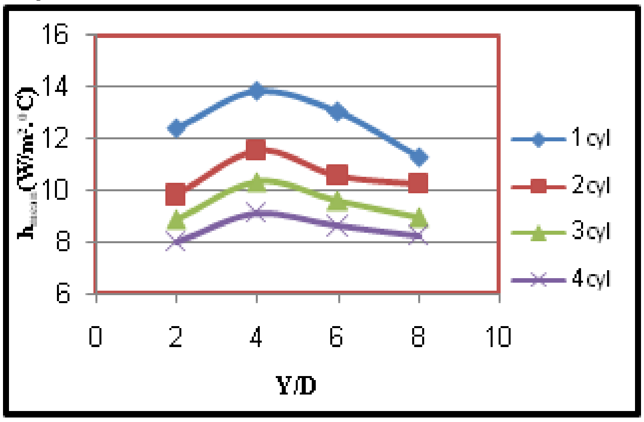


**Figure 10: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=3) ($q^{\approx}$=832 W/m$^2$).**

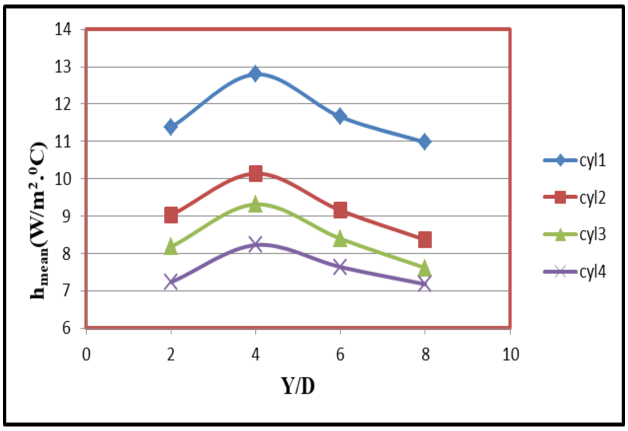


**Figure 11: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (Y/D) at (X/D=3) ($q^{\approx}$=573W/m$^2$).**

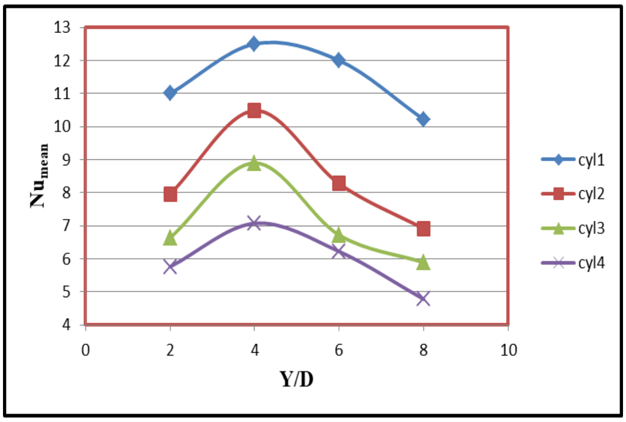


**Figure 12: Distribution of the Mean Nusselt Number of the Cylinders for different value of (Y/D) at (X/D=3) ($q^{\approx}$=188 W/m$^2$).**

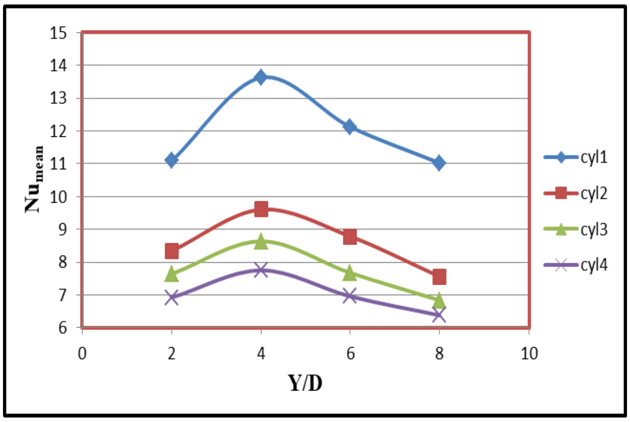


**Figure 13: Distribution of the Mean Nusselt Number of the Cylinders for different value of (Y/D) at (X/D=3) ($q^{\approx}$=341 W/m$^2$).**

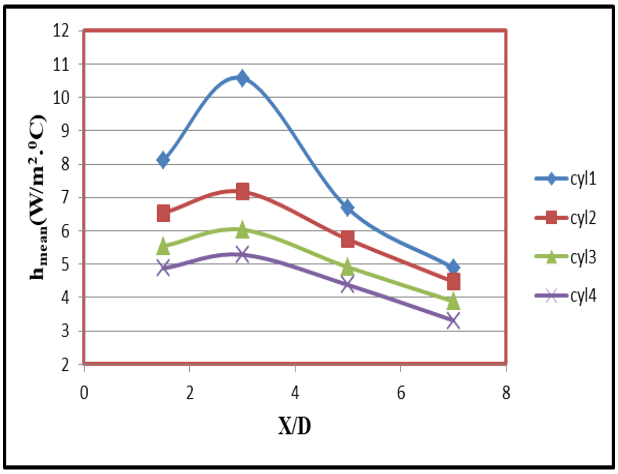


**Figure 14: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=2) ($q^{\approx}$=188 W/m$^2$).**

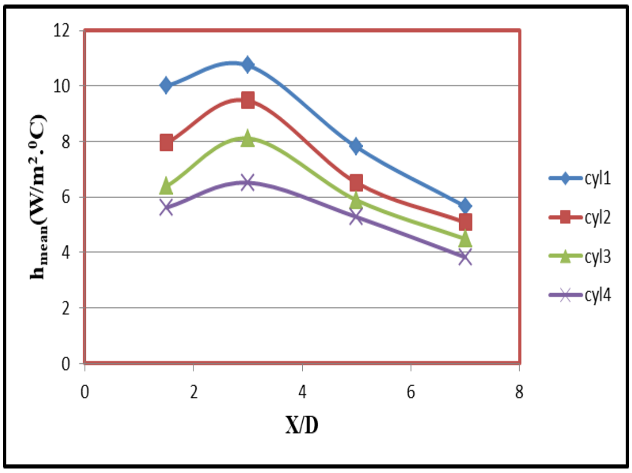


**Figure 15: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=4) ($q^{\approx}$=188 W/m$^2$).**

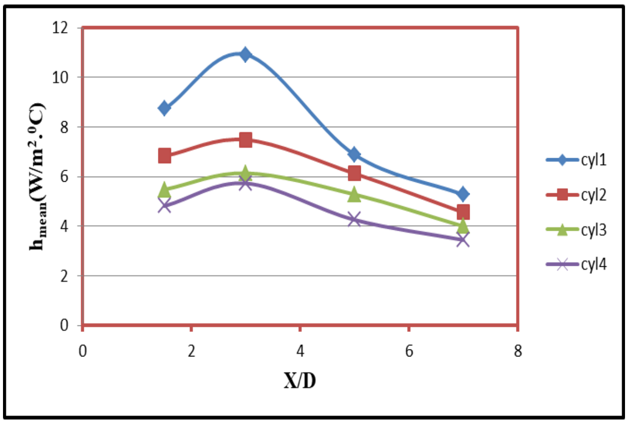


**Figure 16: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=6) ($q^{\approx}$=188 W/m$^2$).**

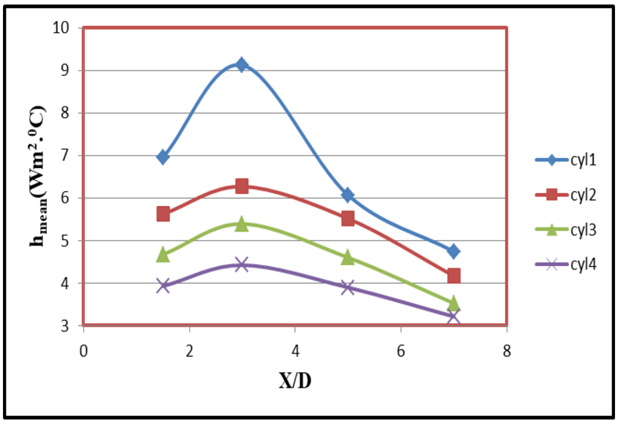


**Figure 17: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=8) ($q^{\approx}$=188 W/m$^2$).**

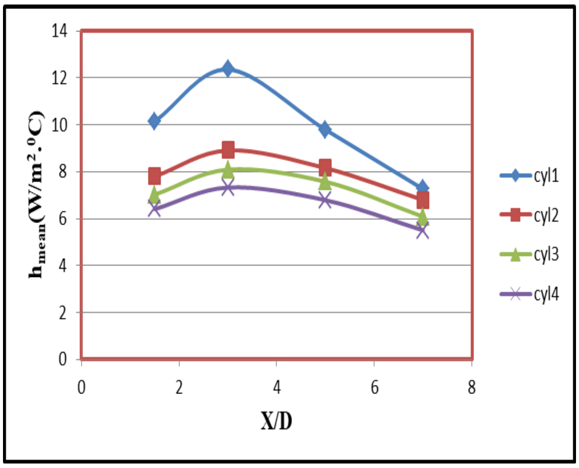


**Figure 18: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=4) ($q^{\approx}$=341 W/m$^2$)**

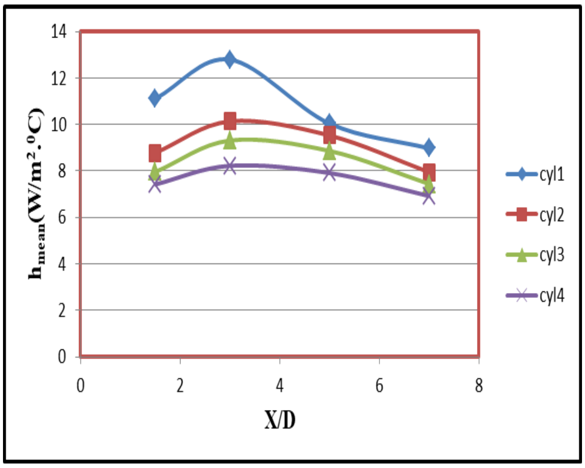


**Figure 19: Distribution of the Mean Heat Transfer Coefficient of the Cylinders for different value of (X/D) at (Y/D=4) ($q^{\approx}$=573W/m$^2$)**

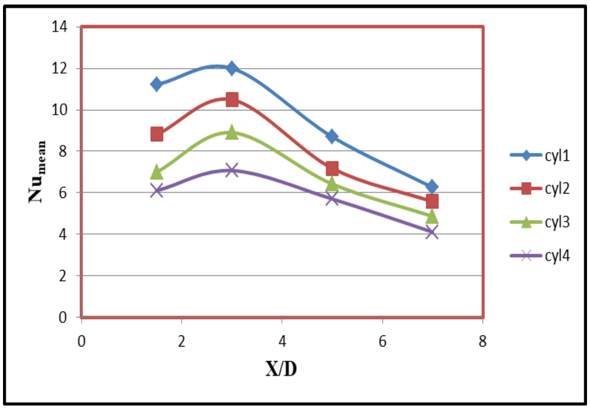


**Figure 20: Distribution of the Mean Nusselt Number of the Cylinders for different value of (X/D) at (Y/D=4) ($q^{\approx}$=188 W/m$^2$).**

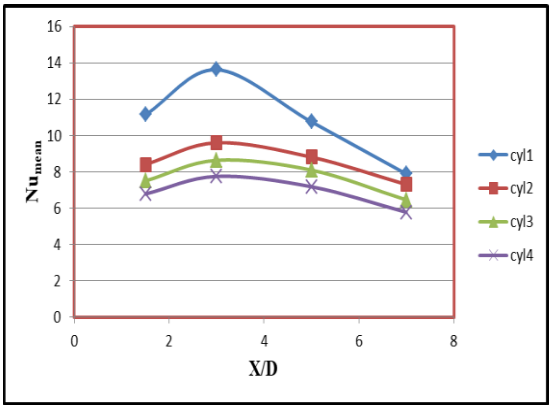


**Figure 21: Distribution of the Mean Nusselt Number of the Cylinders for different value of (X/D) at (Y/D=4) ($q^{\approx}$=341 W/m$^2$).**

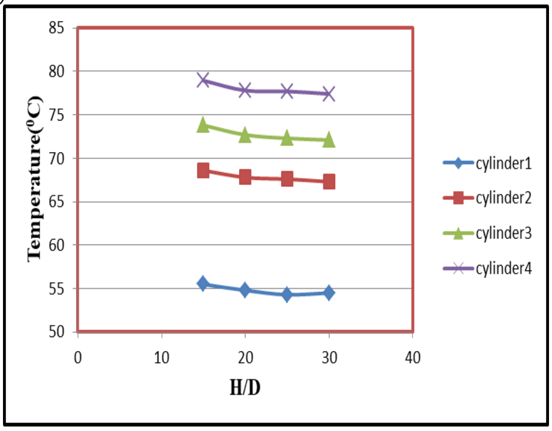


**Figure 22: Distribution of the Mean Temperature of the Cylinders for different value of (H/D) at (Y/D=4, X/D=3) (q̃=376 W/m²)**

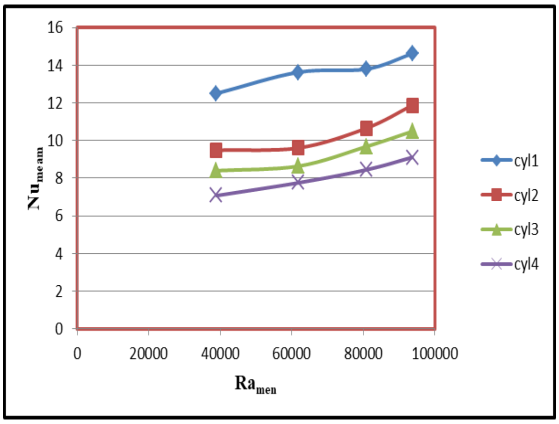


**Figure 23: Variation of the Mean Nusselt Number with the Mean Rayleigh Number at (X/D=3) at (Y/D=4)**

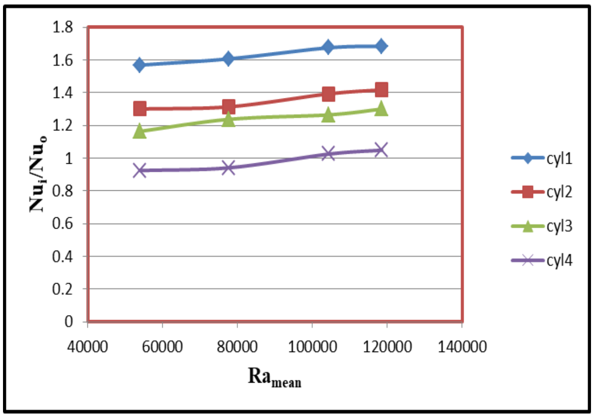


**Figure 24: Comparison of the Mean Nusselt Number between Cylinders in Array and Single Cylinder in Free Stig [3]**

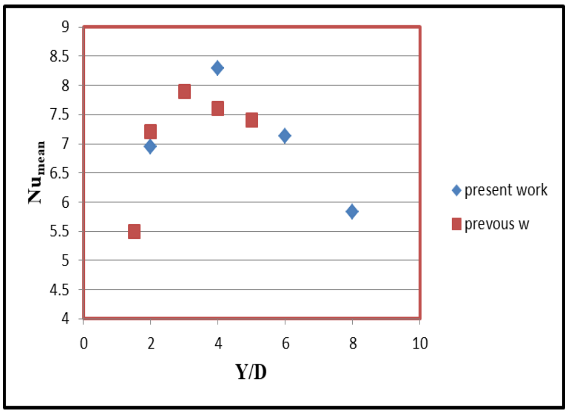


**Figure 25: Comparison between the Present Study and Mean Nusselt Number for different Cylinder at (Y/D=4) & (X/D=3) with different (Ra) Center Separation Distances**

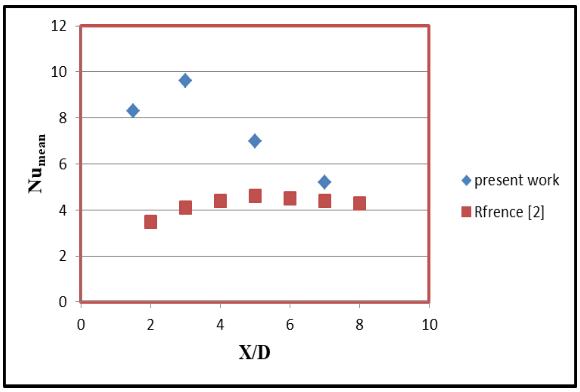


**Figure 26: Comparison between the Present Study and Yousefi Hannani [1] for Mean Nu for different Separation Distances [9] between the Cylinders and the Walls.**

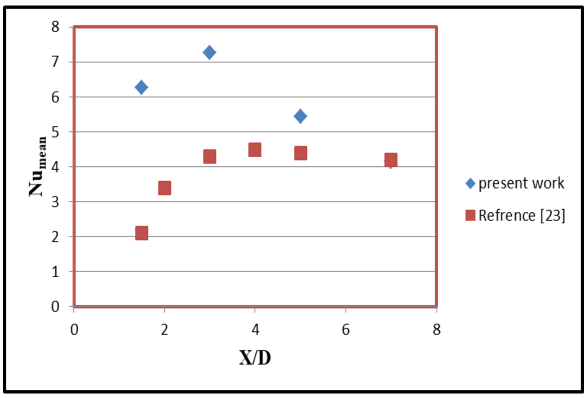


**Figure 27: Comparison between the Present Study and Yousefi Hannani [1] for Mean Nu for different Separation Distances [9] between the Cylinders and the Walls.**

Comparing the varied distance between cylinders and the walls (X/D) with Hannani et. al.[1] &Yousefi et. al. [9] for mean value of Nusselt number of cylinder, it can be observed that Nusselt number have the same behavior where all studies showed, the Nusselt number increases with increase in the distance between cylinders, until reaches the maximum value at optimum distance and then there was degrease in Nusselt number with increase in the distance, as shown in figures 26 and 27.

## 5. CONCLUSIONS

- The increase in (Y/D) increase the heat dissipation from cylinders approaching to maximum value at (Y/D=4), and any increasing or reducing about this ratio leads to reduce the heat dissipation.
- The increase in (X/D) increase the heat dissipation from cylinders approaching to maximum value at (X/D=3), and any increasing or reducing about this ratio lead to reduce the heat dissipation.
- The change in (H/D) ratio shows, there was no obvious influence or simple influence.
- General empirical equation includes (Y/D, X/D) Rayleigh number, concluded as follows:

  $$\mathbf{Nu_{men} = 0.\ 0.765\ Ra^{0.2}\ (Y/D)^{0.08}\ (X/D)^{0.01} \quad (5X10^4 \leq Ra \leq 11.5X10^4)}$$

- comparing between the cylinders placed in vertical array inside conduit with singular cylinder placed in free air at the best case (Y/D=4) & (X/D=3), it was clear there was good enhancement in heat transfer, in case, the cylinders are placed in vertical array inside conduit, comparing with singular cylinder placed in free air. The maximum enhancement reaches to (68%) at (Ra=11.5 x104) for optimum distance between the cylinders and the optimum distance between the walls.
- The heat transfer enhancement increases with increasing Rayleigh number.

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